

Alternative Packaging Study

Lunar Surface Systems BAA
Collaborative Technical Exchange
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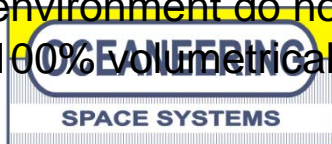
Agenda

- Introduction
- Study Overview
- Summary of Interim Review
- Summary of Final Outbrief
- Topical Highlights
- Phased performance approach for Cx Packaging
- Reference Packaging Concepts



Introduction

- **NASA solicited a study to reduce overhead mass and residual volume for packaging of portable supplies with specific interest in sustainability**
- **Objective:**
 - **Improve the efficiency of loose equipment packing**
 - Identify alternative packing options that **eliminate or minimize waste generation** from packing materials and allow optimal utilization of available stowage volume
 - **For example:**
 - Concepts that require NO packing material
 - Materials that can be volume-reduced after use
 - Materials with secondary application
- **Challenges:**
 - Loose equipment items require special packing to attenuate vibration and loads experienced during launch
 - Historically, approximately 30% of stowage volume lost due to fit mismatch and need for packing foam
 - Much of this packing material is not needed once on orbit becomes a substantial component of the waste stream
 - Packing of clothing and similar items that are not affected by launch environment do not require supplemental packing material and are nearly 100% volumetrically efficient.



Introduction (cont.)

- OSS proposed a broad-reaching study. Proposed scope included:
 - Portable supplies
 - Consumable resources
 - Systems hardware
 - Pressurized and unpressurized applications
- We adopted a holistic approach:
 - Identify high-leverage recommendations for packaging which will have sustained value when embedded in the Cx architecture
 - Identify implications of packaging concepts on Constellation element design and operation
 - Identify innovative design and operational solutions which maximize value over time
- NASA later expressed a particular interest in sustainability:
 - **Program sustainability:** To what extent can effective packaging solutions *contribute to the sustainability and growth of the Constellation program?*
 - **Technical sustainability:** To what extent can effective packaging :
 - *simplify and streamline operations*
 - *improve mass and volumetric efficiency*
 - *promote a technically and operationally sustainable architecture*



Introduction

Packaging is many things to many people...

pack-ag-ing : n. The act, process, industry, art, or style of packing.
Material used for making packages.

The manner in which something, such as a proposal or product, or someone, such as a candidate or author, is presented to the public.

pack-age: noun, verb, -aged, -ag-ing.

-noun 1. a bundle of something, usually of small or medium size, that is packed and wrapped or boxed; parcel. 2. a container, as a box or case, in which something is or may be packed. 3. something conceived of as a compact unit having particular characteristics: That child is a package of mischief. 4. the packing of goods, freight, etc. 5. a finished product contained in a unit that is suitable for immediate installation and operation, as a power or heating unit. 6. a group, combination, or series of related parts or elements to be accepted or rejected as a single unit. 7. a complete program produced for the theater, television, etc., or a series of these, sold as a unit.

verb (used with object) 8. to make or put into a package. 9. to design and manufacture a package for (a product or series of related products). 10. to group or combine (a series of related parts) into a single unit. 11. to combine the various elements of (a tour, entertainment, etc.) for sale as a unit.

**Initial emphasis
must focus on
what packaging
DOES, not what it
IS.**

**The function of
packaging is**



To Protect and to Serve...

Generic Definition

Protect:

- to defend , guard , cover or shield from injury or danger.
- to provide, or be capable of providing, protection

Serve:

- to be in the service of; work for
- to be useful or of service to; help
- to answer the requirements of; suffice
- to contribute to; promote: to serve a cause
- to carry and distribute
- to provide with a regular or continuous supply of something.
- to gratify (desire, wants, needs, etc.)
- to operate or keep in action (a gun, artillery, etc.)

Contextual Definition

Constellation Packaging protects:

- Contents from environments and users
- Environments and users from contents
- Limited resources from loss or waste
 - Transported mass
 - Pressurized and unpressurized volume/accommodations
 - Crew time
 - Energy
 - Budget
 - Schedule

Constellation Packaging serves:

- The crew: by presenting equipment and supplies in an operationally efficient form
- The architecture: by satisfying transportation, distribution, and operational requirements with minimal overhead cost in resources
- Exploration missions: by ensuring availability of resources when and where needed
- The Exploration enterprise: by minimizing costs and maximizing value over time



Summary : Interim Review

Oceaneering delivered a complement of Topical Papers addressing a broad spectrum of packaging considerations consistent with our proposal:

- **Parametric packaging proportions**
 - **Defining constraints and drivers for standardized proportions**
- Barrier-Free Environment
 - Preserving operational flexibility and responsiveness
- Packaging Lifecycle Analyses
 - Understanding opportunities to maximize value while minimizing impact on resources (mass, volume, crew time)
- **Food and Waste Packaging**
 - **Minimizing the penalties for sustaining the crew**
- Metrics
 - Understanding what matters and when
- **Analogs**
 - **Seeking applicable lessons and innovations**
- High-energy fluids as ECLSS feed stock
 - Reducing the logistics demands for life support through efficient consumables and packaging
- Energy Packaging (batteries)
 - Seeking optimal systemic solutions to maximize performance per unit resource
- Lunar Sample Return Packaging
 - Minimizing the cost per unit of sample returned while preserving sample integrity
 - Identifying design considerations for Surface Systems, Altair, and Orion
- Simulation Concepts
 - Understanding how packaging concepts perform in simulated practice

Items in bold text are among the highlights discussed later



Summary: Final Outbrief

Oceaneering delivered another complement of Topical Papers addressing a preferred spectrum of packaging considerations identified during the Interim Review:

- **Terrestrial Analogs**
 - Focus on ultra-light-weight and compact applications
- **Edible Packaging Materials**
 - Identify candidates and potential applications
- 1/6 G as a Contributor to Efficient Packaging
 - Understanding the inherent opportunities of the operational environment
- **Distinctions between Cx vs. STS/ISS packaging**
 - Understanding why the ISS approach won't cut it for Lunar missions
- Polyethylene Packaging for Exploration
 - Exploring the potential value of a highly versatile material
- **Modular Stowage Enclosure Concepts**
 - Deriving concepts for instances where rigid containment is required
- **Lifecycle Implications for Efficient Packaging**
 - Understanding how packaging optimization works over time
- **Stowage Curtain Concepts**
 - Deriving a soft packaging paradigm that scratches lots of itches

Items in bold text are among the highlights discussed later



Selected Topical Highlights

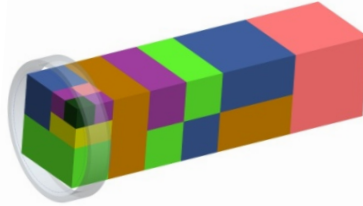
- Proportions
- Food and Waste Packaging
- Edible Packaging Concepts
- Analogs



Parametric Proportioning Concept

Architecturally constrained example based on 32 inch LIDS hatch

Standard rigid-package increment is derived from hatch constraint (diagonal dimension is diameter minus clearance)



Maximum contiguous package envelope 21 x 21 x 84 (encompasses 95% male)

Rectilinear constraints apply to rigid assemblies and packages

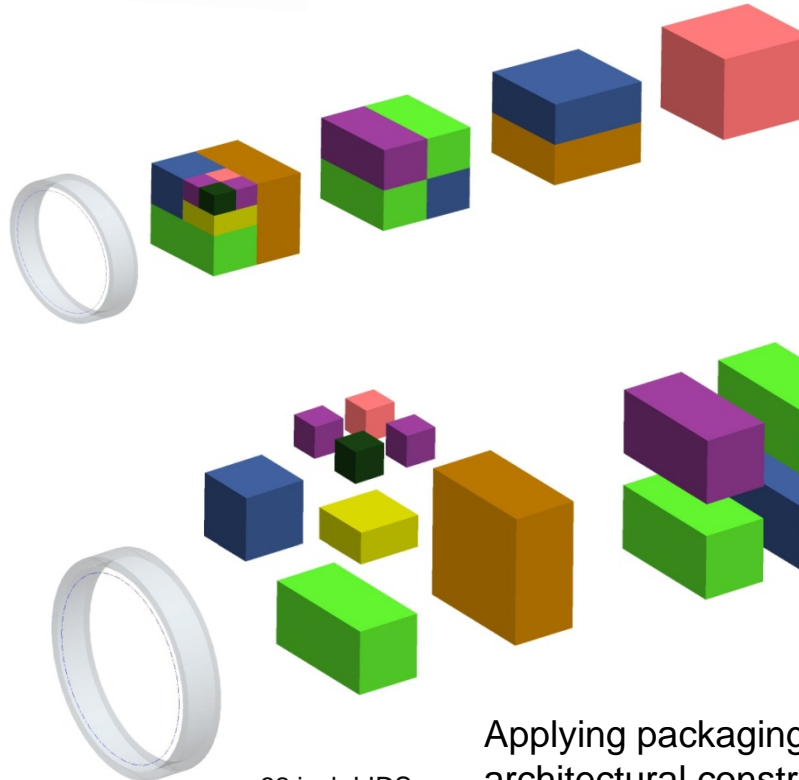
“Soft” packaging must also conform to architectural constraints

Sub-increments of fractional proportions

Minimum increment determined by “granularity” of inventory management and onset of compatibility with “soft-packaging” options

Super-increments of even multiples

Maximum increment equates to human scale



32 inch LIDS hatch

Standard increment proportion
21 x 21 x 21 inches
>~.125 m³

Applying packaging proportions that are immune to architectural constraints will promote operational responsiveness



Food and Waste Packaging

- Premises:
 - food is but a means to package nutrition
 - **Packaging should provide nutritional and hydration needs combined with means to manage metabolic waste**
 - identify a systemic approach which minimizes mass and volume.
- We explored **a minimalist approach to supplying nutrition** to the crew in a manner than minimizes packaging overhead
- Our recommendations **offer menu diversity while not precluding additional food options**



End-to-End Packaging for Human Nutrition

- Comprises Food/Drink and Waste Packaging from Launch to Disposal
- Food/Drink Packaging
 - Transport
 - Storage
 - Preparation
 - Consumption
 - Cleanup
- Metabolic Waste Packaging
 - Collection
 - Food packaging waste
 - Wet food/fecal waste and used wipes
 - Urine and waste drink
 - Respiration/perspiration water
 - Waste Treatment
 - Potable water recovery from wastewater
 - Wet solid waste bio-stabilization
 - Storage and Disposal



The Merits of Dehydrated Food/Drink/Packaging

- **Nutritional Performance**

- **Great variety** of protein/fruit/vegetable/grain/drink items are available
- Rehydrated **quality** is as good or better than thawed cooked frozen food
- **Shelf life** unopened is 5-30 years with no air exposure (hermetic packaging)
- Shelf life opened and covered, with air exposure, is about nine months

- **Mass Performance**

- Wet foods average about eighty percent water by mass
- So **dehydrated food weighs about one-fifth as much as wet food**

- **Volume Performance**

- Dehydrated food density w/o size reduction is about twice that of wet food
- **Density, with size reduction to powder, is about three times that of wet food**

- **Packaging Performance**

- **Gallon-size bags can hold about 4.4 lbm of food powder, corresponding to 22 lbm of wet food**
- **Gallon-sized resealable metallized (hermetic) plastic bags weigh about 0.1 lbm**
- **So dehydrated food packaging performance is 220 lbm of wet food per lbm of bag**

Food/Drink Rehydrated with Imported Potable Water

- **Water Packaging Performance**

- ISS Contingency Water Carrier (CWC) is flight-qualified to transport potable water
- Each CWC is 18" D x 24" L, weighs 2.95 lbm, and holds 95 lbm of water
- Mass performance is 32 pounds of water per pound of CWC
- Commercial nautical water bags have similar mass performance

- **Daily average mass penalty per person for water supply without MFHE potable water recovery from wastewater is 7.0 lbm, plus 0.22 lbm of packaging**

- **Rehydrated Food Packaging Performance**

- 4.4 lbm of dehydrated food/drink can be transported in a 0.1 lbm bag
- 17.6 lbm of potable water required to rehydrate 4.4 lbm of food/drink powder
- 0.55 lbm of CWC required to transport 17.6 lbm of potable water
- So 0.65 lbm of packaging required to transport 22.0 lbm of rehydrated food/drink

- **Overall performance is 34 pounds of rehydrated food/drink per pound of packaging without MFHE potable water recovery from wastewater**

**PACKAGING PERFORMANCE IMPROVES CONSIDERABLY IF
POTABLE WATER IS RECYCLED FROM WASTE WATER**

Food/Drink Service and Packaging

- **Legacy space mission food management had to be microgravity compatible;** meant individual serving containers with **very high packaging penalties, especially mass**
- **Lunar surface gravity allows use of gravity-enabled methods of food/drink storage, preparation, consumption, and cleanup (The “Gravity Galley”)**
- **Gravity Galley Concept**
 - Transport of all food/drink as dehydrated solids in standard bulk containers
 - Store food/drink as dehydrated solids in standard bulk containers
 - Transfer individual portions from bulk containers to consumption devices
 - Each crewmember has personal drink bottle, wet food tray, and utensils
 - Each crewmember responsible for cleanup of own consumption devices
 - Rehydrate dry food/drink with hot or cold potable water

Waste Management Packaging

- **Waste Collection Concepts**

- **Food packaging waste**

- Empty food-transport bags are reused for wet solid waste collection and storage

- **Wet food/fecal waste and used wipes**

- Collected and stored in empty food-transport bags
 - Food bags compatible with **gravity-enabled dry toilet**, collapsible when not in use.

- **Urine and waste drink**

- Legacy space mission urine collection had to be microgravity compatible
 - Lunar surface gravity allows use of **gravity-enabled unisex urinal**
 - Waste drink collected in urinal for treatment with urine

- **Perspiration/respiration water vapor**

- Legacy space mission water vapor collection had to be microgravity compatible
 - Lunar surface gravity allows use of hydrophobic-coated condensing heat exchanger (no biofilm growth) and gravity-enabled condensate-air separator

Waste Management Packaging - Continued

- **Waste Treatment Concepts**

- Potable water recovery from wastewater
 - Minimizes human metabolic support logistics penalties
 - Metabolic water vapor condensate “polished” by multifiltration (flight-qualified)
 - Urine and waste drink treated by gravity-enabled vapor compression distillation (Smaller and more efficient than ISS flight-qualified microgravity-compatible version)
- Wet solid waste bio-stabilization
 - Feces, wipes, and waste food can be bio-stabilized with small amounts of commercially-available biocide/dessicant/deodorant powder mixes

- **Waste Storage and Disposal**

- Treated wet solid waste contained in sealed food-transport bags (reuse)
- Dry solid waste contained in dry material transport bags (reuse)

Edible Packaging Concepts

- Potential Applications

- Void fillers
- Corner protection
- Environmental sealing
- Load distribution
- containment

- Conclusions

- Edible substances may be useful as packaging to cushion fragile contents
- Their properties for such applications are unsubstantiated
- Combinations of edible and non-edible packaging may prove effective

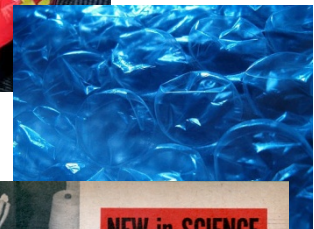
- Recommendations

- Additional study should determine the properties and potential applications for these and other candidates
- Further study may identify opportunities to develop improved candidates

Candidates



- Dehydrated foods
- Edible Paper, Ink, fabrics and films
- Popcorn
- Rice cakes
- Beans and Lentils
- Semi-consumable materials(e.g. filled bubble-wrap)
- Sausage
- Wax-coated cheese
- Engineered Foods?



Topical Highlights: Analogs

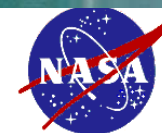
- **OSS examined multiple analogs**

- Bass boats
- Fire Trucks
- Ambulances
- Med-Evac Helicopters
- Gadget Bags
- Luggage
- Motorcycle touring
- Ultra-light Backpacking
- Sailing
- Bicycle Touring



- **Take-away messages**

- Fabric-based packaging offers high utility per unit resource
- Optimal value favors delivery, storage, and operational deployment using a single package
- Shedding artificially-imposed “requirements” promotes efficiency



Observations from Analog Research

- Packaging technology has advanced since Apollo, and will continue to advance prior to Cx missions. Cx architecture must remain open to advancing technology.
- Carefully assess mission and lifecycle to identify optimization opportunities
- The weighting of metrics influences optimal packaging for any application
- Versatility minimizes overhead
- “Substance over Style” : avoid artificial constraints on form and function
- Fabric solutions are highly effective in mass/volume critical applications
- Optimal dispersal of packaging is critical on performance sensitive vehicles
- Generic packaging is wasteful as compared to optimized point designs
- Generic accommodations for packaging are favorable
- Innovative design and operational solutions may eliminate packaging altogether



Analog: Observations (cont.)

- Packaging must endure environments, protect contents, then either “disappear” or offer ongoing value as a resource
 - Provide mission phase-specific performance and endurance
 - Substantially contribute to operational efficiency once at the point of use
 - Apply materials offering supplemental ongoing value
- Packaging itself should constitute a planned and integral architectural element
 - Providing dedicated stowage accommodations in addition to packaging is wasteful
 - Packaging which acts as operational storage eliminates storage-related hardware and transfer operations
 - Packaging applied as environmental outfitting may supplant permanent outfitting
 - Versatile packaging can help maximize the utility and efficiency of hosting elements
 - Allocating all protective capabilities to packaging disregards opportunities to provide protection at a higher level to reduce down-stream penalties associated with peak environments
 - Analogy: STS rigid Payload Retention Latch Assemblies
 - Analogy: Air-ride trailers
 - Providing “soft-ride” interfaces between launchers and payloads may enable significant improvements in payload mass-fraction and reduction in structural mass-fraction to the lunar surface
- Efficiency is not achievable by placing the entire burden on the packaging
- Holistic efficiency will be promoted by mutually beneficial packaging, contents, and accommodations designs



**WHAT ABOUT ISS AS AN
ANALOG?**



Distinctions: STS/ISS vs Lunar Applications vis-à-vis Packaging

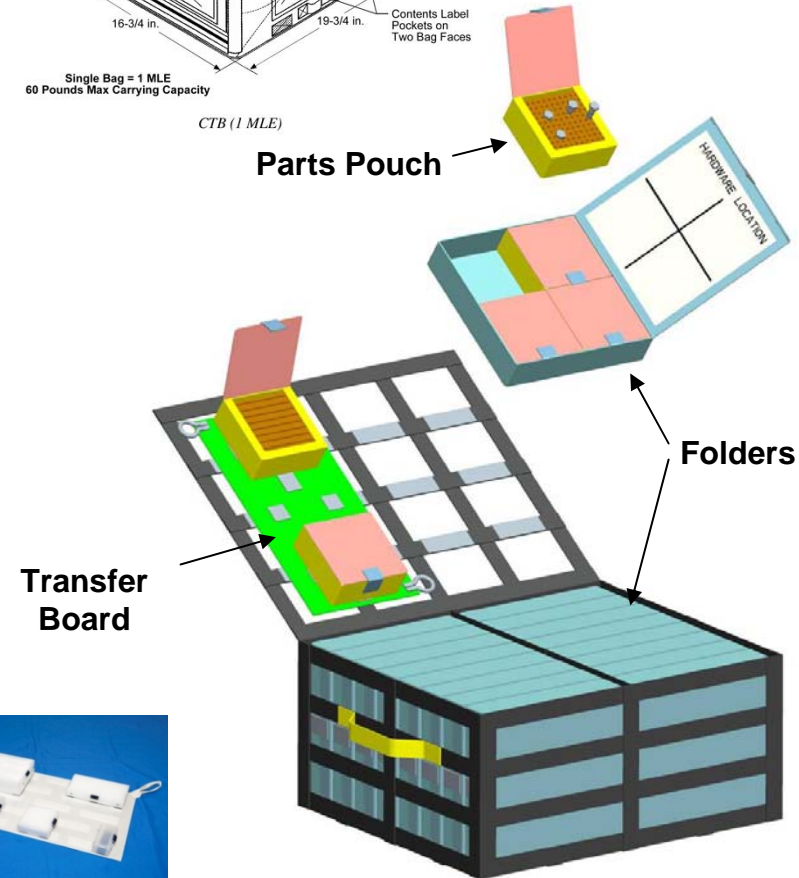
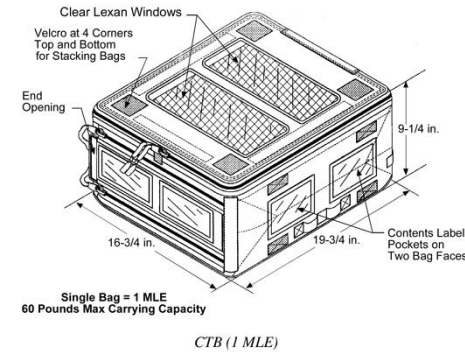
- STS/ISS packaging serves a distinctly different architecture and mission model than Cx
 - Reusable packaging may be applied for multiple missions
 - Bi-directional transport is less constrained (at least until STS retirement)
 - Multi-axis loading, restraint and containment are constant requirements
 - Transport is aboard a human-rated vehicle
 - Application occurs in 0-g environment
- Lunar environments present distinct challenges and opportunities as compared to LEO missions:
 - End-user Cx packaging functions occur exclusively in a gravity environment where objects can hang in a stable condition and can be assumed to remain at rest unless acted on by crew
 - Potential exposure to lunar contaminants
 - Surface area versatility is constrained by the gravity field (no “floating over” objects or “working on the ceiling”)
 - ONE-WAY-TICKET: once delivered to the moon, Cx hardware is NEVER* coming back
- STS/ISS packaging solutions can’t offer the efficiency potential required Cx applications

*Given the cost of return and scarcity of recoverable payload mass, nothing will be returned from the moon unless its value exceeds the cost of its return and the value of alternative returnables



ISS packaging evolution...

- ISS packaging uses large quantities of Nomex cloth and Pyre foam to create and fill-out standardized external proportions
- Residual packaging represents a huge burden aboard ISS
- Increasingly efficient options are still in development (example: CRAVE-DO-35 IVA Tool Kit)
 - Webbing exterior contains folders and provides temporary fixation for deployed contents
 - Nomex internal “Folders” contain pouches
 - Teflon “pouches” contain maintenance components
 - L200 Minicell foam retains individual contents
 - “Transfer board” provides deployment surface
- **But, even with continued design improvements:**
 - ISS missions and environments are a poor analog for Constellation lunar missions and environments
 - The CBT-MDK proportional paradigm should be dropped in favor of greater volumetric efficiency using a packaging solution optimized for lunar missions and environments



Phased Packaging Performance



OSS explored “Phased Performance “ concepts

- Objectives
 - Account for ALL processes through which missions are realized to ensure holistically optimized packaging performance
 - Develop packaging which satisfies functional and performance requirements for specific serial life-cycle phases
 - Minimize or eliminate penalties in future phases associated with performance requirements associated with prior phases
 - Realize crew-interactive capabilities only in end-use environments
- Intended advantages:
 - Minimize down-stream penalties once each mission phase has been endured
 - Avoid continued application of resources to sustaining/transporting obsolete capability
 - Endure mission phases with adequate margins only in the configurations applied during said phases
 - Adapt to subsequent mission phases (e.g. reconfigure, combine, deploy, etc.)
 - Prioritize performance metrics on a phase-by-phase basis and seek the optimal balance of performance on a case-by-case basis
 - Promote highly efficient hosting architecture and operations
 - Maximize residual value

Following charts provide a generic discussion. Later charts revisit the concept with reference to a particular design concept



Phased performance: General Overview

Mission Phase	Preferred Packaging Attributes	Design Implications
Packaging Design Engineering	<ul style="list-style-type: none"> •Capability to accommodate all transportable equipment using simple variations on a theme •Ability to apply reliable materials and processes to design and create packaging 	<ul style="list-style-type: none"> •Cx package designs will reflect greater point-design optimization to achieve the required levels of efficiency •Design themes and philosophies will be optimized in place of a generic standard packaging configurations
Pre-launch Processing and Manifest Management	<ul style="list-style-type: none"> •Ability to manage packaging in 1-G •Ability to adapt packaging to accommodate unexpected delivery requirements 	<ul style="list-style-type: none"> •Implement interoperable packaging and accommodations designs wherein point-design packages behave compatibly with generic hosting vehicles • Preserve ability to alter manifests until late in the launch flow (responsiveness = sustainability)
Installation to Lunar-destined Cx Elements	<ul style="list-style-type: none"> •Packaging integrates to elements with minimal mass and volume “overhead” 	<ul style="list-style-type: none"> •Eliminate secondary structures which offer little or no value through the most extended mission phases (minimize down-stream penalties) •Implement loads and dynamics analytical capabilities that can accommodate indeterminate packaging behavior



Phased performance- cont.

Mission Phase	Preferred Packaging Attributes	Design Implications
Launch	<ul style="list-style-type: none"> •Package, contents, and hosting element must endure launch environments •Mass properties shall favor a controllable and high-performance integrated vehicle 	<ul style="list-style-type: none"> •Promote short and robust load paths •Reduce non-contents-related mass •Promote small MOI •Present favorable dynamic characteristics of contents, packaging, and hosting vehicle •Take advantage of single-axis quasi-static loading (unlike STS where landing loads are on a different vector than launch)
Trans-lunar	<ul style="list-style-type: none"> •Endure low-intensity loiter environments •Endure pressure cycling contingencies 	<ul style="list-style-type: none"> •Zero-g crew operability is NOT a driver for Cx packaging* (unlike ISS/STS) •Transport apart from crew offers design flexibility not available in STS ops environment (cargo poses no direct risks to crew)
Lunar descent	<ul style="list-style-type: none"> •Promote Descent Stage controllability 	<ul style="list-style-type: none"> •Favor designs with minimal mass and favorable MOI •Favor compatibility with low-mass accommodations in Surface Systems
Lunar landing	<ul style="list-style-type: none"> •Withstand landing loads 	<ul style="list-style-type: none"> •Probably encompassed by ability to endure Earth-ascent •Ensure no compromise due to exposure to in-transit contingencies •Recognize high mass fraction of packaged materials aboard landing craft

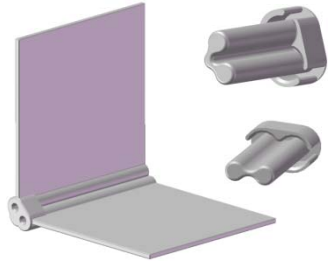
Phased performance- cont.

Mission Phase	Preferred Packaging Attributes	Design Implications
Lunar landing	<ul style="list-style-type: none"> •Withstand landing loads 	<ul style="list-style-type: none"> •Probably encompassed by ability to endure Earth-ascent •Ensure no compromise due to exposure to in-transit contingencies
In Situ Utilization by Crew	<ul style="list-style-type: none"> •Favor rapid deployment •Maintain inventory control •Minimize crew time spent addressing packaging functions •Create a safe and productive environment. •Promote maximum utility from limited habitable volume 	<ul style="list-style-type: none"> •Maintain compatibility with packaging accommodations in various surface systems elements •Implement automated inventory management capabilities •Select environmentally suitable materials (flammability, off-gassing, particulates, etc.) •Create adaptive storage/packaging systems which serve multiple functions
Packaging contents depleted	<ul style="list-style-type: none"> •Enable decrease in packaging envelope as contents are depleted •Create space for fresh supplies as depletion occurs •Maintain package functionality as contents are depleted 	<ul style="list-style-type: none"> •Provide ability to “reef” packaging as contents are depleted •Facilitate adaptation of storage complement for arrival of fresh packages
“Spent” packaging end of service life	<ul style="list-style-type: none"> •Minimize residual materials •Promote secondary value of packaging materials •Minimize crew time associated with depleted packaging 	<ul style="list-style-type: none"> •Promote low-impact accommodations for depleted packaging •Maximize use of in-situ recyclable materials to the extent that resources can support recyclin. •Keep it simple

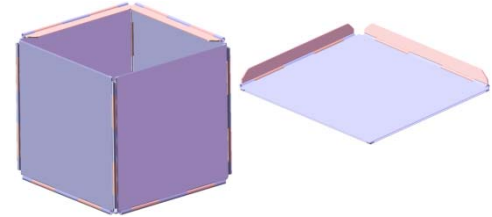
Design Concepts



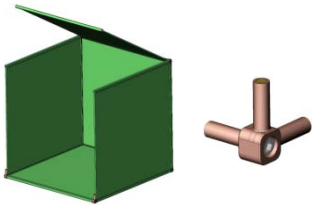
Modular Rigid Container Concepts



- **DOGBONE CONCEPT**
 - Differing panels
 - Alternate attach method for side panels
 - Dog bone cross section rod joins two panels
 - Full length engagement or multiple locations along length

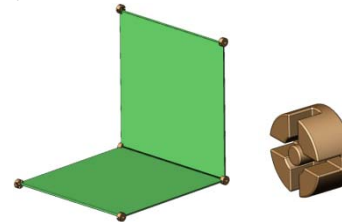


- **HINGED PANEL CONCEPT**
 - Common panels
 - Slide and lock style locking mechanism (not shown)



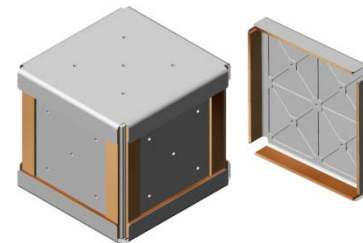
- **PIP PIN CORNER CONCEPT**
 - Common panels
 - Pip pin style locking mechanism
 - Multiple corner designs needed based on final layout

- **TINKER TOY CONCEPT**
 - Differing panels
 - Alternate attach method for side panels
 - Center screw (not shown) provides locking
 - Latching dogs
 - Compressed rubber
 - Alternate corner piece for non-rectilinear configurations



- **LIVING HINGE CONCEPT**
 - Top and bottom panels with Living Hinge
 - Flat side panels with Dual-Lock™ fastening
 - Injection molded polyethylene panels with integrated iso-grid

- **FABRIC HINGE CONCEPT**
 - All panels identical with Dual-Lock™ fastening
 - Fabric hinges with Dual-Lock™ fastening
 - Injection molded polyethylene panels with integrated iso-grid



Modular Rigid Container Concepts: Implications

PROS

- Panels may be adapted by crew to create habitat outfitting
- Potential use of panels as radiation shielding
- Potential to create “hybrid” packaging using fabric and rigid components
- Possible applicability for unpressurized applications
 - Provide assured containment
- Offer definitive structural behavior if required by contents or accommodations

CONS

- Packaging interfaces to contents and encompassing environments introduce potential for inefficiency
 - Increased local loading conditions at rigid interfaces drive designs to that which can under short term environments
 - Void areas within and surrounding containers
- “One-size-fits-all” concepts threaten efficiency
- **Application of rigid enclosures should be the exception rather than the rule**
 - Requirements must dictate the need
 - Otherwise use soft-packaging



Stowage Curtain Concepts

- Based on findings from our broader investigations, OSS developed a reference packaging concept that addresses the “phased-performance” philosophy
- The next few charts illustrate how this concept was derived, how it works, and how addresses phased performance objectives



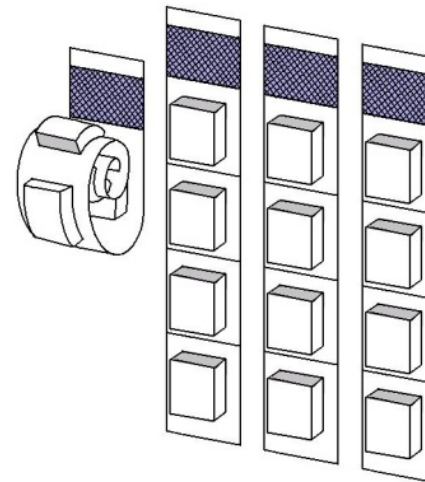
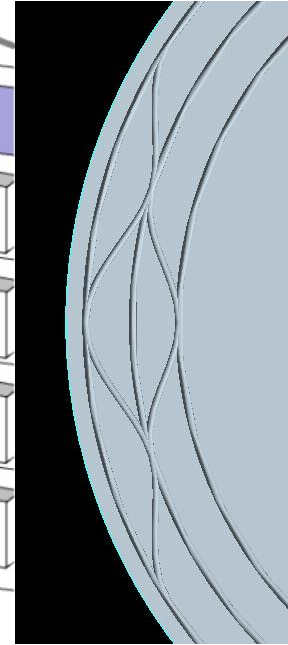
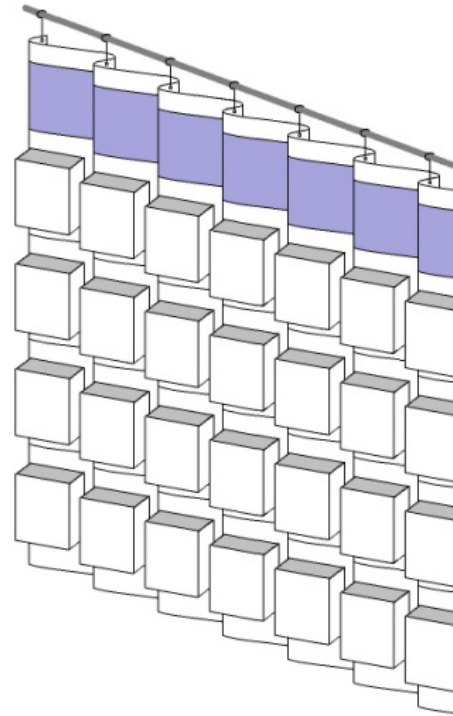
Stowage Curtain Concept

- This concept was inspired by:
 - Terrestrial analogs
 - Phase-weighted metrics concepts
 - Phased Performance concepts
 - Desire to provide packaging, stowage, and operational deployment all using one hardware element
 - Desire to develop an adaptive packaging scheme which applies a common and simple set of interfaces to accommodating elements while being amenable to custom-configured interfaces to contents
 - Desire to promote efficiency and versatility for contents and for accommodating elements



Stowage Curtain Concept (cont.)

- Rolled curtain panels contain and protect contents during delivery phase
- Curtains are deployed by crew to track array on ceiling
- Packaging and habitat outfitting concepts are highly coordinated to reduce mass and complexity while promoting adaptability
- Decks provides support structure for cargo delivery
- Concept favors an “open deck” habitat interior approach
(see next chart)



Curtains may be assembled from individual panels
(vertical panels shown)

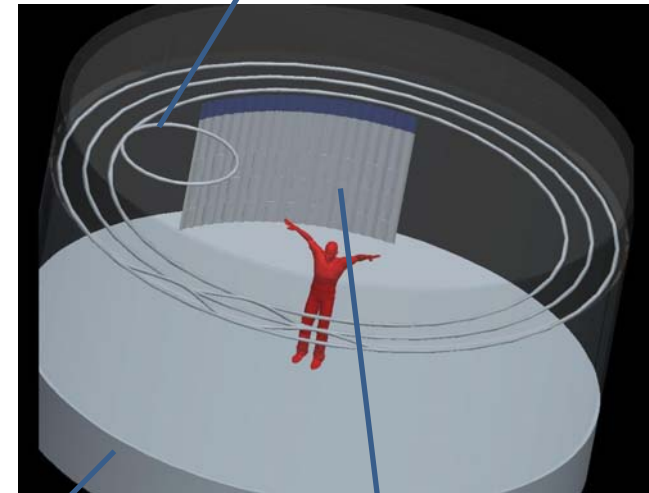
“Open Deck” concept as Supported By Storage Curtains

- Modules are outfitted with thick deck structure (truss)
 - Deck accommodates systems and subsystems installations
 - Accessible from above and below
 - Withstands launch/landing loads from supported cargo
 - Withstands crew loads once in lunar environments
 - Floor and ceiling surfaces provide an array of fixation points for deployable outfitting
- Deployable “soft” outfitting is delivered as cargo
 - Stowable sleeping quarters
 - Deployable work enclosures
 - Positive or negative delta-P
 - Stowable shower
 - Deployable medical workstation/enclosure
- “Hard” outfitting is integral to or deploys from deck or ceiling
 - Drop-down/lift-up galley
 - Localized shower-head/floor drain



NOTIONAL OPEN-DECK INTERIOR

Localized shower curtain track encompasses ceiling-mounted shower head and floor-integrated drain

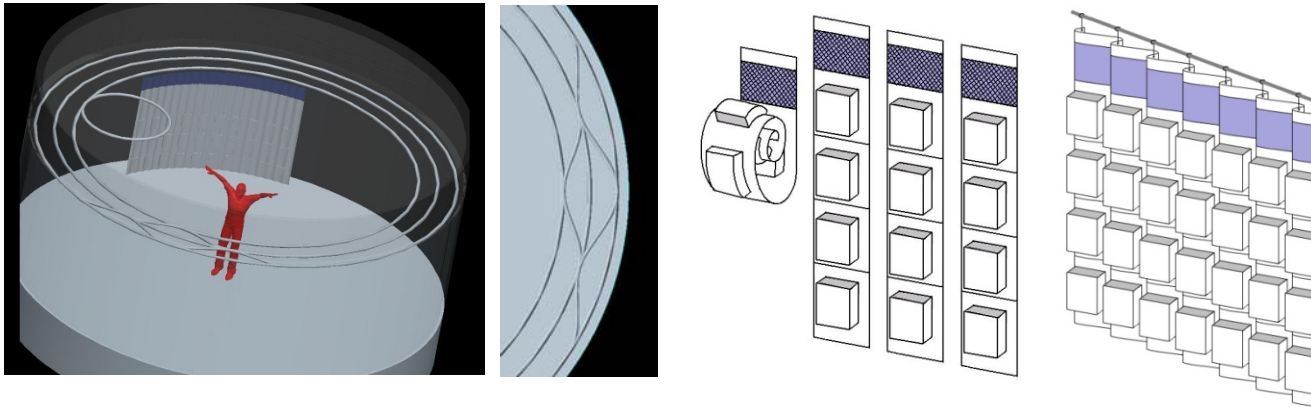


Thick decks provide robust surfaces to deliver cargo and withstand crew loads; contain deployable hard outfitting and systems; provide tracks to support deployed soft outfitting

Deployed curtains hang from rails to provide storage, reconfigure to adapt interior, offer direct access to contents, once depleted, line walls of habitat to provide increasingly effective radiation barrier

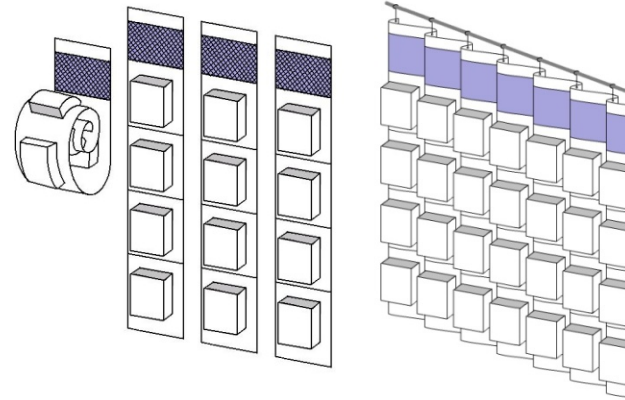
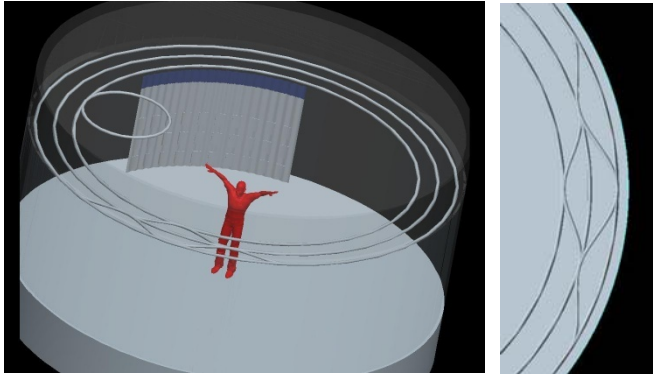


Stowage Curtain Concept: Phased Performance



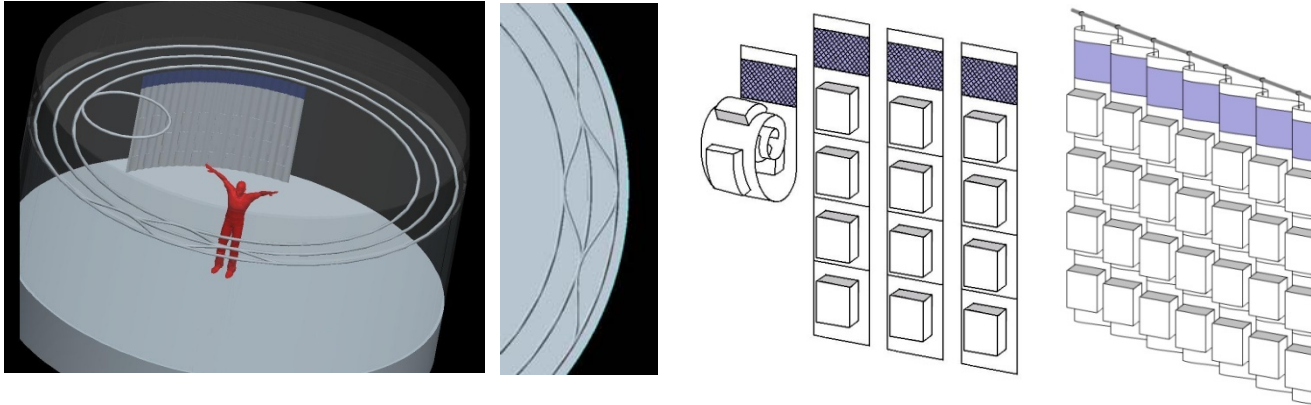
Phase	Preferred Packaging Attributes	Design/operational Implications
Packaging and Element Design, Engineering and Fabrication	<ul style="list-style-type: none"> • Compatible with versatile restraint, containment, and protection methods for a wide variety of contents • Familiar materials and fabrication techniques • Simple assembly with fewer details than CTBs • Packaging requires simple interfaces on accommodating elements 	<ul style="list-style-type: none"> • Individual package designs are variations on a common theme • Small investment in case-by-case optimization returns significant reduction in transported mass • Behavior of “rolled” curtains may not vary much with changes in contents. • May eliminate need to develop and deliver permanent storage accommodations aboard lunar surface elements.

Stowage Curtain Concept: Phased Performance



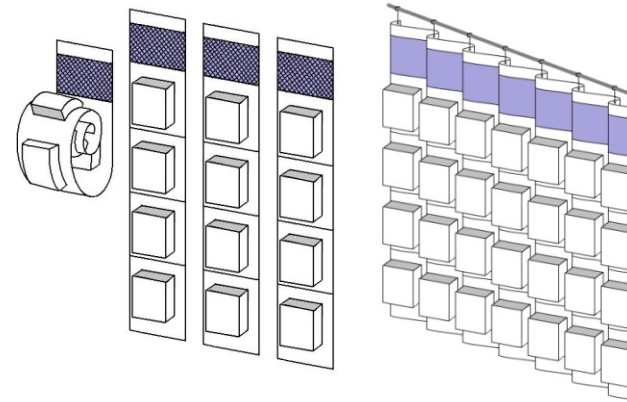
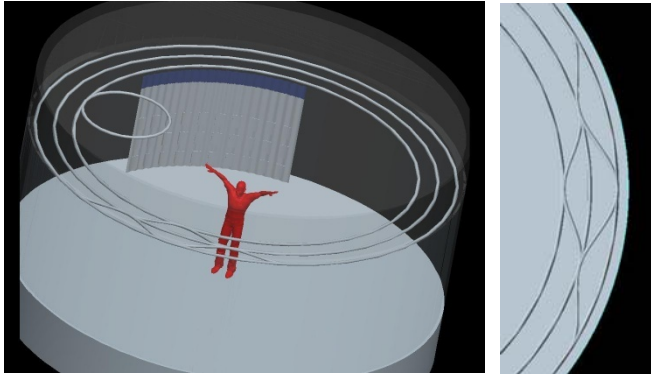
Phase	Preferred Packaging Attributes	Design/operational Implications
Pre-launch Processing and Integration	<ul style="list-style-type: none"> • Packages are manageable in 1-G • Packages easily accommodate predicted and unexpected delivery requirements • Packages behave predictably within the limits of generic and simple accommodating structures (easily manifested cargo) 	<ul style="list-style-type: none"> • Carriers provide robust generic accommodations • Deck-supported cargo requires no “rotisserie” to reorient modules during cargo installation (unlike MPLM). • Approach favors individual “padding” of contents to result in less volume attributable to void-fillers” • Approach does not limit potential application of edible packaging materials or other recommendations from the Packaging study. • Versatile/adaptable/simple packaging and accommodation approach promotes late manifest changes

Stowage Curtain Concept: Phased Performance



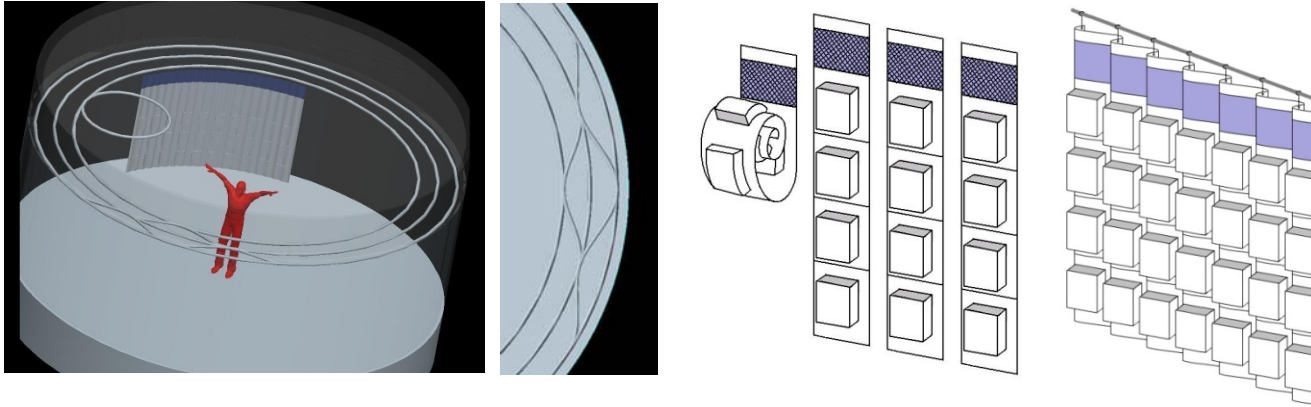
Mission Phase	Preferred Packaging Attributes	Design/operational Implications
Installation to Lunar-destined Cx Elements	<ul style="list-style-type: none"> •All pressurized elements will have a “floor” of some sort, thus providing commonly configured cargo accommodations throughout the architecture • Unpressurized elements can also provide horizontal planar surfaces to accommodate similar storage curtain configurations 	<ul style="list-style-type: none"> •Ceiling and floor-based accommodations for delivering and deploying curtains leave wall surfaces available for alternative emplacements (workstations, etc.) •Low-residual packaging provides greater capacity in lunar assets for replenishment with subsequently delivered material

Stowage Curtain Concept: Phased Performance



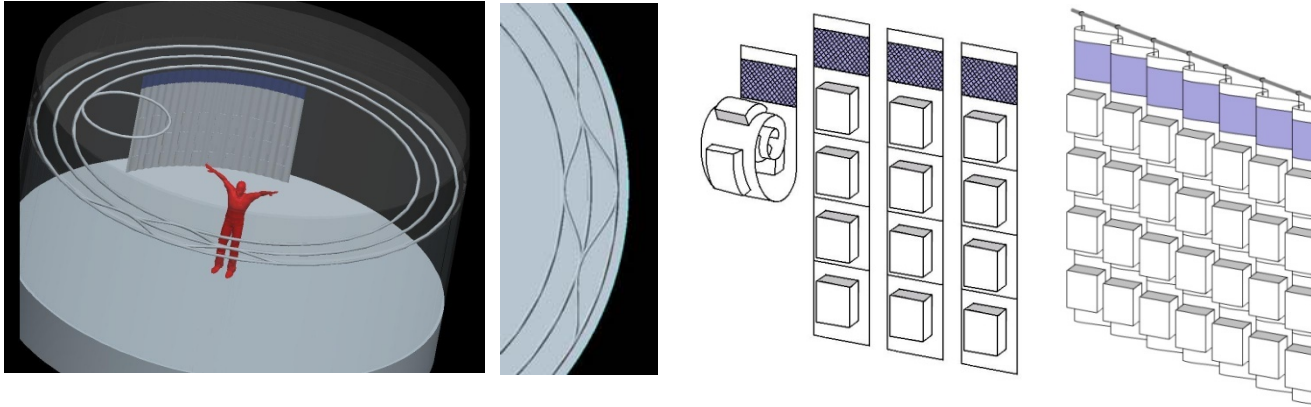
Mission Phase	Preferred Packaging Attributes	Design Implications
Launch	<ul style="list-style-type: none"> • Direct support of packaging on deck minimizes instances where contents bear on other contents • Planar/horizontal cargo accommodations surface favors simple and versatile restraint configurations for alternative cargo complement on recurring missions • Elimination of variable secondary structures on recurring launches simplifies analysis for launch environments • Deck structure is applied in a phase-optimized manner across launch, landing, and lunar surface phases 	<ul style="list-style-type: none"> • Rolled curtains on supportive deck involve short and direct load paths through robust structures • Combined packaging and storage function reduces mass • Optimal distribution of packages on deck enables favorable MOI to be achieved • Takes advantage of the fact that all principal accelerations occur along a common axis (launch, TLI burn, LO burn, landing burn, and lunar contact) • Utilizes a limited complement of structures to support cargo during launch and transport, and support crew-imposed loads once in use.

Stowage Curtain Concept: Phased Performance



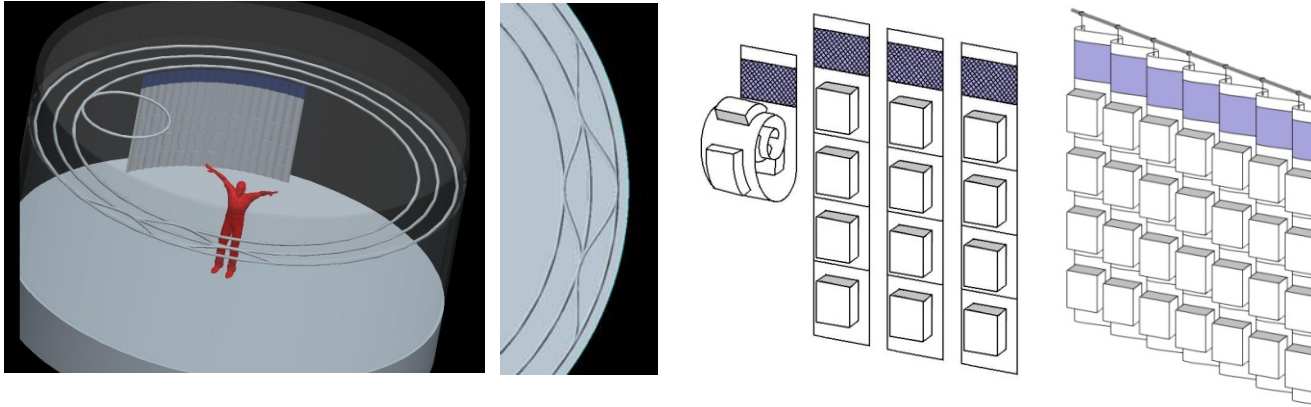
Mission Phase	Preferred Packaging Attributes	Design Implications
Trans-lunar	<ul style="list-style-type: none">• Endure low-intensity transit environments.• Endure pressure cycling contingencies	<ul style="list-style-type: none">• Rolled curtains can maintain contents under compression (as applicable) without resorting to encapsulation/evacuation techniques• Rolled curtains may be compatible with applications aboard CEV, including transfer with crew between CEV and Altair

Stowage Curtain Concept: Phased Performance



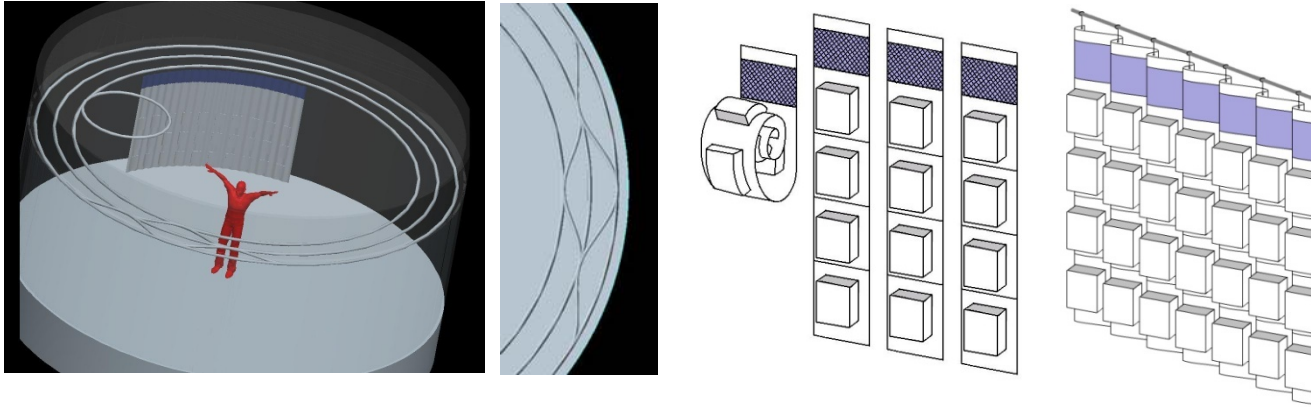
Mission Phase	Preferred Packaging Attributes	Design Implications
Lunar descent	Promote Descent Stage controllability and performance	<ul style="list-style-type: none">• Offers potential to reduce tare weight of packaging vs. contents to increase functionality per pound of landed mass

Stowage Curtain Concept: Phased Performance



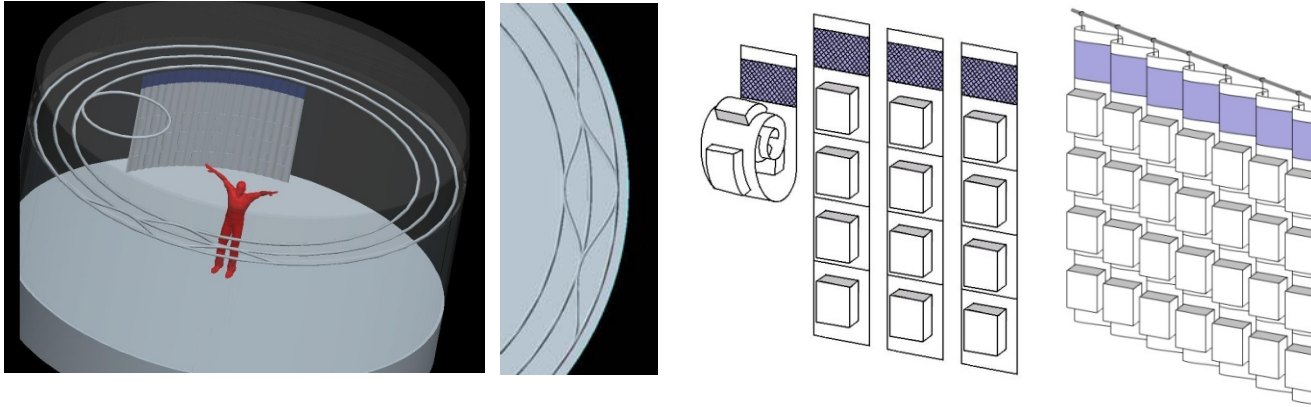
Mission Phase	Preferred Packaging Attributes	Design Implications
Lunar landing	<ul style="list-style-type: none"> • Deck-supported packages present well-distributed loads to phase-loaded structures • Deck-supported packages contribute to low CG and can be located to provide axial CG and minimize MOI • Packages restrained firmly to deck remain well controlled through all dynamic flight phases 	<ul style="list-style-type: none"> • Concept promotes reduction in the structural mass for surface-destined elements • Robustness requirements are encompassed by ability to endure Earth-ascent

Stowage Curtain Concept: Phased Performance



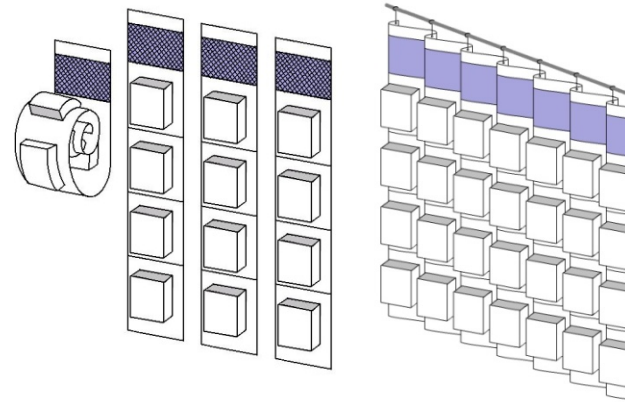
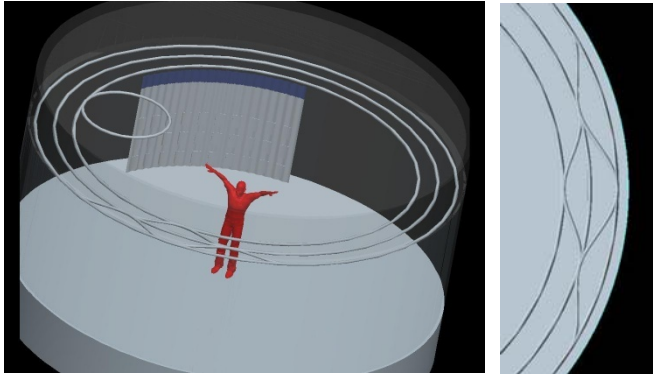
Mission Phase	Preferred Packaging Attributes	Design/operational Implications
In Situ Utilization by Crew	<ul style="list-style-type: none"> • Simple 1/6 G compatible deployment without removing contents • Direct access to contents (minimizes “nested” packaging) • Compatible with RFID tracking of deployment array, curtains, and contents • Inherently safe soft outfitting • Adaptive complement of outfitting and storage promotes utility of limited habitat volume 	<ul style="list-style-type: none"> • Avoids relocation of contents from delivery to storage accommodations. • Incremental deployment of curtains enables modulation of habitat volume over time • Special-performance fabrics offer supplemental value in special applications (e.g. “Safe Haven” packaging concept) • Unpressurized applications are simple enough for gloved hand operation, and may favor deployment of low-mass EVA worksites via simple/minimal deployment interfaces

Stowage Curtain Concept: Phased Performance



Mission Phase	Preferred Packaging Attributes	Design /operational Implications
Packaging contents depleted	<ul style="list-style-type: none"> • Packaging gets smaller as contents are depleted • Planar curtain assemblies utilize minimal amount of fabric • Curtains comprise interior walls, partitions, outfitting • Crew can adapt interior in response to changing needs 	<ul style="list-style-type: none"> • Polyethylene fabric is effective radiation shield • Alternative colors and designs offer interior décor options • Curtains offer stowage for other depleted packaging • Curtains may be rolled or folded into compact configurations • In unpressurized applications, curtains deployed around ascent craft may function as ejecta barriers

Stowage Curtain Concept: Phased Performance



Phase	Preferred Packaging Attributes	Design/operational Implications
“Spent” packaging: end of service life and extended functionality	<ul style="list-style-type: none"> • Depleted packaging becomes peripheral radiation barrier 	<ul style="list-style-type: none"> • Accessible features of depleted packaging continue to provide storage accommodations <ul style="list-style-type: none"> • No residual stowage accommodations • Module capacity is not limited by availability of storage provisions or capacity at delivery: Pressurized Logistics Modules may evolve into “warehouses” • “Temporary aisles” provide access as required with minimal dedicated free volume

Stowage Curtain Concept (cont.)

- Other optimization opportunities include:
 - Using engineered fabrics to provide application-supportive performance in curtain assemblies
 - Anti-microbial fabrics: promote healthy environment
 - CO₂ scrubbing fabric
 - potentially applicable to Safe Haven “go pack” for ECLSS contingencies
 - Go-pack contains O₂ candles, CO₂ scrubbing capability, thermal blanket, and consumables provisions
 - Each crewmember may be allocated a “go pack” that will sustain one person for a TBD period of time
 - Transparent films: potentially useful for interior partitions
 - Sound-attenuation: potentially useful for deployable sleeping quarters
 - Radiation attenuation: contribute to establishment of a localized radiation safe haven or generally reduce flux in habitat
- Using evacuation of trapped air to reduce volume and/or influence pre-load on contents
- Use of tracks and deck interfaces to host other deployable habitat enhancements
 - Deployable/stowable workstations, showers, medical exam room, etc.



Conclusions



- Mass and volume reduction for portable equipment packaging are but two objectives
 - PACKAGING OPTIMIZATION at a higher level is the “grail”
- Cx element, systems, and component designs must support the packaging approach if great efficiency is to be achieved over the program lifecycle
- No single packaging design will efficiently meet every application
 - Invest in case-by-case optimization based on a common theme
 - Marginal additional DDT&E cost will be more than offset by reduced operating costs
- By combining all of these concepts and more in an appropriate manner, significant improvements may be achieved vs. ISS/STS packaging, with concurrent improvement in overall value and functionality





Take-away Message



- Optimal packaging influences every aspect of the Cx architecture, not just the containment of portable supplies
- The packaging concept must be coordinated with the element, component, systems design and operational concepts to ensure mutual compatibility and mutual net benefit
- A Packaging Working Group would be instrumental in defining, mandating, and monitoring/advocating adherence to a universally applicable/beneficial packaging paradigm of the Cx architecture
- Unpressurized packaging is as much a challenge as pressurized packaging, and demands additional dedicated study to ensure mutually optimal performance across the Cx architecture

